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4.
GLACIAL PHENOMENA

J. R. Campbell

IN MAINE.

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1867.*

March 4. 1873.

By LOUIS AGASSIZ.

*Sent to the
Duke of Argyll.*

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BOSTON:
TICKNOR AND FIELDS.
1867.



14 Feb 1867

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My dear Campbell

I send a pamphlet
by Cassin that may interest
you. He sent me a bundle
of them. Also a ticket
to be used or not on an
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Ever truly

André Ramsey

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of the latter as they successively fell
upon the glacier, and were borne along
upon its back, retaining all the sharp-
ness of their angles, because they were
subjected to no pressure; the charac-

Feb 19. 1867. and 21st

For my own opinions on this subject
and for my own observations on
glacial Phenomena ^{in Canada and} over a
very wide tract in America.

From Hamilton Inlet in
Labrador to St Louis on
the Mississippi; to Washington,
Boston, the Green Mountains,
White Mountains, the Catskill
Mountains; and other places
see "A Short American Tour"
and "Frost & Fire".

I am perfectly satisfied
that in Canada & America
glaciation extends at
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The piles of drift & water
worn stones on the Atlantic
sea-beach extending to a
great height on the flanks
of the mountains: Terraces
and other marks prove
to demonstration that a
sea covered all the low
lands of Europe & ^{North} America
at a very late Geological period.
Previous to this Marine period
^{according to} Agassiz, Ramsay, Geikie
and their school which includes
Lukes ^{and Croll} I believe. The earth
was covered by a polar glacier
which was 10,000 feet
thick in Maine. - For this
read James Croll who
gives dates for the Glacial Period.

GLACIAL PHENOMENA IN MAINE.

THREE or four years ago I began a series of papers in the "Atlantic Monthly," which, though they appeared as separate geological sketches, had, nevertheless, a certain sequence. These contributions have been unavoidably interrupted for more than two years; and, in taking up the thread again, my readers will excuse me if I recall to them the point at which we parted, by a rapid review of the subject then under discussion. There were two sets of facts which first awakened the attention of geologists to the ancient extension of glaciers, though at first no investigator connected them with the agency of ice. The first was the presence of boulders in Central Europe and England, which had their birthplace far to the north of their actual position; the second was the presence of similar detached boulders scattered over the plain of Switzerland, and on the slopes of the Jura, which, on the contrary, had travelled from the south northward, and had their origin in the Alps. Before they attracted the attention of scientific men, these dislodged masses were so generally recognized as strangers to the soil, that in Germany, among the common people, they went by the name of *Fündlinge*,—homeless children. They are indeed the wandering Bohemians among rocks.

The first interpretation of these phenomena, which very naturally suggested itself, when they began to be systematically studied, was that of their transportation by water. It was supposed that irruptions of the northern oceans had swept the loose masses of Scandinavian rock over adjoining countries,

and that large lakes within the Alps had broken their natural barriers, and poured down into the plains, carrying with them *débris* of all sorts, and scattering them over the lowlands. But soon it was found that this theory did not agree with the facts; that the valleys of the Alps, for instance, had sent out boulders, not only northward, but southward and westward also, and that their distribution was often so regular, and their position so isolated, on high elevations, as to preclude the idea that immense tidal waves, freshets, or floods had so arranged them. Nature is so good a teacher that, the moment we touch one set of facts, we are instinctively, and almost unconsciously, led to connect them with other phenomena, and so to find their true relations. The boulders of the plains soon began to be compared with the boulders of the higher valleys; ice itself was found to be a moving agent; and it was presently ascertained that the transportation of loose materials by existing glaciers, and their mode of distributing them, corresponded exactly with the so-called erratic phenomena of Central Europe and England. With these results were soon associated a great number of correlative facts;—the accumulation of loose materials under the glacier, and upon its sides, as well as upon its surface, the trituration of the former until they were ground to a homogeneous paste, and the regular arrangement of the latter as they successively fell upon the glacier, and were borne along upon its back, retaining all the sharpness of their angles, because they were subjected to no pressure; the charac-

teristic markings, furrowing, grooving, scratching, and polishing of the surfaces over which the glacier passed, as well as of the pebbles and stones held fast in its mass, and coming into sharp contact with the rocks beneath; the accumulation of loose materials pushed along by the advancing ice, or carried on its edges, and forming ridges or walls at its terminus and on its sides. The study of these combined results of glacial action now became part of the subject, and were sought for by geologists wherever the erratic phenomena were investigated. Out of these comparisons has gradually grown a belief that, as the Alpine glaciers were formerly more extensive, so did the northern ice-fields, now confined to the Arctic regions, once stretch farther south. I suppose there are few geologists now who would not readily give their assent to the glacial theory, expressed in this general form.

But while the wider distribution of glacial phenomena from mountainous centres in ancient times is now generally admitted, the theory in its more universal application, involving, that is, the existence of an ice-sheet many thousands of feet in thickness moving across whole continents, over open, level plains as well as along enclosed valleys, still meets with many opponents, the staunchest of whom stand high as geological authorities. If not openly said, it is whispered, that, after all, this great ice-period is a mere fancy, worthy at best of a place among the tales of the Arabian Nights; that no morainea have ever been noticed in North America; and that what has been ascribed to the agency of terrestrial glaciers, upon this continent, is simply the work of icebergs stranding against a coast which has subsequently been raised, so that the boulders first deposited by the floating ice along the shores now lie inland at a great distance from the sea. According to this suggestion all the erratic phenomena in North America, the extensive sheets of drift, the continuous and prominent ridges of drift materials, the larger scattered boulders, the

scratched, polished, and grooved surfaces, are the work of floating ice, poured forth, then as now, from the Arctic regions. If this be so, we should expect to find all these so-called traces of glacial action running from the coast inward.

Let us see now how this agrees with the facts. I will not recapitulate the substance of my last article on this subject, "The Ice-Period in America." It gave a general summary of the glacial phenomena on this continent, as compared with those of Europe, stating at the same time my reasons for believing that immense masses of ice would move over an open plain nearly as rapidly as in a slanting valley, and from the same causes as those which determine the advance of the Swiss glaciers down the Alpine valleys. This article appeared in June, 1864. I had intended to follow it with one upon the appearances of the drift in this country; and in September I went to Maine in order to examine the drift phenomena on the islands and coast of that State, and compare them with those of the Massachusetts shore. It was my purpose to go directly to Mount Desert, but the loss of a carpet-bag detained me at Bangor. What seemed at first a vexatious annoyance proved in the end to be a fortunate chance; for, while waiting at Bangor, I fell in with a friend, who, when he heard the object of my journey, proposed to me to pass the intervening day or two in a drive with him northward along the "horse-backs," in the direction of Mount Katahdin. I desired nothing better; for a previous glimpse of one horseback, in the neighborhood of Aurora, had already shown me their morainic character, and they therefore were immediately connected with my present investigation. It would give me, besides, an opportunity of carrying out my survey on a much larger plan. As I had already satisfied myself, in this and previous journeys from Portland to Bangor, that the traces of glacial action occurred over all that region, this excursion would enable me to follow them

to a considerable distance northward, while on my return I could track them down to the coast in continuous connection. I dwell upon the character of this investigation, because, numerous as have been the local observations of this kind, I am not aware that extensive tracts of land have been systematically surveyed, compass in hand, with the view of ascertaining the continuity of these marks in definite directions. I gladly accepted my friend's offer; and to this incident I owe some of the pleasantest days I have ever spent in traveling, and the knowledge of some important, and I believe novel, facts in glacial phenomena, an account of which will be found in the present article.

It was late in September, just at the turn of the leaf; the woods were in all their golden and crimson glory, with here and there a purple beech, or a background of dark-green pines. Familiar as we all are with the brilliancy of the autumnal foliage in the neighborhood of our towns, one must see it in the unbroken forest, covering the country with rainbow hues as far as the eye can reach, in order to appreciate fully its wonderful beauty. A few words on this change of color, which is as constant as any other botanical character, (each kind of tree having its special tints peculiar to itself, and not reproduced by other kinds,) may not be amiss. Indeed, not only does every species have its appointed range of color, but each individual tree has its history told more or less distinctly in the ripening of the foliage. A weaker or a younger limb may have put on its autumn garb, and be almost ready to drop its leaves, while the rest of the tree is untouched. A single scarlet maple or red oak often gives us the most beautiful arrangement of tints, from the green of mid-summer, through every shade of orange and red; in the same way one leaf may ripen unequally, its green surface being barred or spotted with crimson or gold for days before the whole leaf turns. These differences give ample opportunity for studying the ripening process. In attempting to determine

the cause of these changes, it ought not to be forgotten that they occur locally, and also make their appearance on particular trees much earlier than upon others; so early, indeed, as to show clearly the fallacy of the prevalent idea that they are caused by frost. The temperature remains ten or fifteen degrees above the freezing-point for a month and more after a good many of our trees have assumed their bright autumnal hues. The process is no doubt akin to that of ripening in fruits; especially in such fleshy fruits as turn from green to yellow, purple, or red, like apples, peaches, plums, cherries, and others. The change in color coincides with changes in the constitutive chemical elements of the plant; and this comparison between the ripening of foliage and fruit seems the more natural, when we remember that fruits are but a modification of leaves, assuming higher functions and special adaptations in the flower, so as to produce what we call a fruit. The ripening process by which the leaves take on their final colors is as constant and special as in the fruits. The cherries do not assume their various shades of red, deepening sometimes into black, or the plums their purples, or the peaches their velvety-rose tints, or the apples their greens, russets, browns, and reds, with more unvarying accuracy than the different kinds of maples and oaks, or the beeches, birches, and ashes, take on their characteristic tints. The inequality in the ripening of the foliage alluded to above has also its counterpart in the fruits. Here and there a single apple or peach or pear ripens prematurely, while all the rest of the fruit remains green, or a separate branch brings its harvest to maturity in advance of all the surrounding branches. No doubt the brilliancy of the change in the United States, as compared with other countries, is partly due to the dryness of the climate; and indeed it has been observed that certain European flowers take on deeper hues when transplanted to America. But I believe the cause lies rather in the spe-

cial character of certain American plants and trees. The Virginia creeper, for instance, which is much cultivated now in France and Germany, turns to as brilliant a scarlet in a European garden as in its native woods.

But let us return to our horsebacks. At the very beginning of our journey, we followed one of them for a considerable distance after leaving Bangor, on our way to Oldtown, besides which we saw a number of similar ridges running parallel with it.* The name is somewhat descriptive, for they are shaped not unlike saddles with sloping sides and flattened summits. They consist of loose materials of various sizes, usually without marked evidence of a regular internal arrangement, though occasionally traces of imperfect stratification are perceptible. Sometimes they follow horizontally, though not with an absolutely even level, the trend of a rocky ledge; again, they themselves seem to have built the foundation of their own superstructure, being composed of the same homogeneous elements which cover the extensive flats over which they run with as great regularity as upon a more solid basis. The longest of these horsebacks—and they sometimes stretch, as I have said, for many miles—trend mainly from north to south, though their course is somewhat winding, seldom following a perfectly straight line. They are unquestionably of a morainic nature, and yet they are not moraines in the ordinary sense of the term, but rather ridges of glacial drift heaped up in this singular form, as if they had been crowded together by some lateral pressure. Had they been accumulated and carried along upon the edge of a glacier, they could not be found in their present position. They differ also from moraines proper in their rounded materials, containing many scratched and polished pebbles, while moraines are built chiefly of angular fragments of

rocks. Neither can they have been accumulated by currents of water; for they occur in positions where any flood passing over the country, far from producing such an arrangement, must have swept them away, or at least have scattered them and destroyed their ridge-like character. They are, indeed, identical with the bottom glacial drift, that is, with the materials collected beneath the present glaciers, and ground to a homogeneous paste by their pressure and onward movement. I would call such accumulations *ground moraines*, that is, moraines formed completely under the glacier, and resting immediately upon the rock or soil beneath. Of course, masses of drift below a great sheet of ice, moving steadily in the same direction over uneven, rocky surfaces, cannot preserve the same thickness throughout. Here and there the incumbent weight will press more heavily in one direction than in another, thus crowding the loose materials together, rolling them into ridges following mainly the direction of the movement. Occasionally such uneven pressure may drive these materials up, from either side, along the summit of a rocky ledge, or heap them at any height upon its slope. We have seen that the horsebacks, though uneven and winding, usually run from north to south; but occasionally also they trend from east to west. This is the case where a morainic accumulation of loose materials may have been pushed forward, along the margin, in front of an extensive sheet of ice moving southward, and then left unchanged by the subsequent retreat northward of the whole mass. I conceive that such horsebacks, running east and west, may be compared to terminal moraines, which, as is well known, owe their origin to oscillations of the front end of a glacier, pushing forward a mass of loose materials, thus throwing it up into a transverse ridge, and then melting away to some point farther back. I have already shown, in previous articles, how such walls are constructed, often forming concentric

* Those who wish to follow the localities indicated in this article should consult H. F. Walling's map of the State of Maine, published by J. Chace, Jr., Portland.

ridges one within another, each of which marks a retreating step of the glacier. Sometimes the summit of the horsebacks is so broad and even that the country people consider them as natural roads, and build their highways along them. They are indeed occasionally so symmetrical that they have been taken for artificial Indian mounds. The most perfect one I have seen stretches through Lagrange township, between Bangor and Mount Katahdin, its direction being mainly from north to south.

Leaving the horsebacks and the open country on the second day of our drive, we entered upon a more wooded region, which brought us through the townships of Lagrange and Brownville, to the Ebeeme Mountains, at the foot of which the Katahdin Iron Works are situated. This is not only a very picturesque spot, but a most interesting locality with reference to glacial phenomena. To the north of the Iron Works there are two ranges of hills, one to the east, the more prominent masses of which are respectively known by the names of Horseback and Spruceback, while to the west corresponding summits have been christened the Iron Mountain and Chairback. These two ranges are separated by a depression called the Gulf, at the foot of which, between Horseback and Iron Mountain, there lies a little lake. Here a practised eye will at once detect the unmistakable action of a glacier in two successive periods of its history. In the direction of Iron Mountain and the Chairback, one hundred feet and more above the level of the lake, may be seen old lateral moraines, more or less disintegrated, marking an ancient glacial level. At a much less height, indeed but little above the bottom of the valley, a magnificent crescent-shaped terminal moraine is thrown across the southern end of the lake. By this wall the waters drained from the whole valley are held back to form a lake, although the barrier is not perfectly impassable, for a little stream oozes through it, just in front. Evidently

this moraine is an accumulation of loose materials, pressed forward by the great local glacier once filling the Gulf, at the time when the ice was circumscribed within the limits of the valley itself. To the east and west of it there are, however, lateral moraines, resting on a much higher level, and showing the extraordinary thickness of the glacier at a still older period. This structure is almost identical with that of the morainic accumulations in the trough holding the present glacier of the Upper Aar in Switzerland. At its extremity stands a large, crescent-shaped moraine, corresponding in size and form almost exactly to that of the Katahdin Iron Works. The loose materials thrown on either side of the valley, to the right and left, extending in advance of the front moraine, and resting far above the present surface of the ice, may be compared to the higher lateral moraines of this ancient Maine glacier. In short, were the ice suddenly to disappear from the Alpine valley in which the Aar glacier lies, the rocky frame-work of loose fragments it has built around itself would be almost identical with that of the so-called Gulf at the Katahdin Iron Works. In both instances, the lateral moraines on a higher level indicate an earlier phase in the history of the glacier, when the ice was thicker; while the terminal moraine records the wasting of the glacier, until it occupied a much smaller area. As the Gulf is an interesting locality for the study of ancient glacial phenomena in Maine, I must point out its bearings with more precision, for the benefit of those who may care to verify my statements by personal observation. To the east of the hotel there is a knoll, on which stand the smelting-works. This knoll itself forms a part of the moraine; but its character may be more distinctly appreciated from the shore of the lake, looking toward the smelting-works. In this position, the abrupt inner side of the crescent-shaped wall faces the observer.

The traces of this local glacier in two successive phases of its existence are not more distinct than are those of the

great ice-sheet in which all lesser glaciers were once merged, over the whole region. And not here alone. I have tracked its footsteps on its southern march from the Katahdin Iron Works to Bangor, and thence to the sea-shore. Every natural surface of rock is scored by its writing, and even the tops of the mountains attest, by their rounded and polished summits, that they formed no obstacle to its advance. It has been assumed by some geologists, and especially by Sir Charles Lyell, that the ice-period was initiated by the spread of local glaciers from special centres. The particular character of the more extensive glacial phenomena satisfies me, on the contrary, that they must have preceded in course of time all mere local glaciers, and that the latter are but the remnants of the great ice-sheet lingering longer in higher and more protected valleys. From the evidence we have of its thickness and extent, such a mass of ice advancing over the country would have swept away all evidences of local glaciers, all morainic accumulations previously formed. I therefore infer that the local phenomena were the latest in time, and consequent upon the shrinking of the larger continuous ice-sheet. It is my belief that the ice-period set in, as our winters now do, — only upon a gigantic scale, — by snow-falls, and that it faded as do our winters, leaving local patches of ice wherever the temperature was favorable to their preservation.

I may say, without exaggeration, that glacial phenomena extend over the whole length and breadth of the State of Maine, wherever there is no obvious cause for their disappearance. One word of explanation, that this assertion of their omnipresence may not seem overdrawn to those who follow me over the same ground, expecting, perhaps, to find the glacial writing at every step along the roadside, and to see the polished surfaces as shining and slippery as a metallic plate or a marble slab. In the first place, all kinds of rock do not admit the same degree of polish. Coarse and friable sand-

stone cannot be polished under any circumstances. Only the finer granitic rocks retain the striae and the polished surfaces very distinctly, in this region; and even upon these they are frequently hidden by the accumulation of soil, or occasionally obliterated by decay, where the rock is not hard enough to resist the atmospheric influences. The loose materials themselves, which have served as emery to grind down, polish, and groove the surface of the soil, may eventually become a screen to cover it from observation. The skill of the geologist consists in tracing these marks from spot to spot over surfaces where they were once continuous. When I say that I followed the glacial marks, compass in hand, from north to south, over a line a hundred miles in length, I do not mean that I never lost sight of them for that distance; but simply that one set of lines, which always ran due north and south, unless deflected, as we shall see, by some local cause, usually explicable on the spot, might be traced at intervals over all the rocky surfaces. If they disappeared under a stream on its northern shore, they reappeared on the southern side; if hidden for a time by some mass of vegetation, they were found again farther on; and thus—allowing for natural and inevitable interruptions—it may be correctly said that they are continuous over the whole country. The glaciated surfaces—to express in one word the combined action of glaciers on the rocks over which they move—present the most varied outlines, sometimes flat, sometimes bulging, with inclined slopes. But whether more or less prominent, they are always rounded, dome-shaped, and the larger furrows, like the smaller striae and grooves, are invariably straight. Never do we find winding, branching furrows determined by the inequalities in the hardness of the rock, or by pre-existing fissures, as is the case wherever rocks are worn by water, or rather by sand and pebbles set in motion by water.

While upon the subject of glacial phenomena in general, and in order

not to interrupt too frequently the account of my own journey, I may here enumerate some of the localities in the State of Maine where glacial marks are most distinct. They are so numerous, that I must limit myself to those where the traces are most remarkable. To the east of Portland there are a number of ledges where they are well preserved, and they exist also upon some rocky surfaces in the islands of the bay. Rocky ledges occur frequently between Yarmouth and Lewiston, the surface of which is polished and scratched from north to south. These ledges are partly covered by morainic accumulations. West of Lewiston, along the Little Androscoggin, there is a coarse clay slate distinctly scratched in the same way. To the east of Lewiston, along Lake Winthrop, there are surfaces of clay slate intersected by greenstone dikes exhibiting also the characteristic markings; and an immense median moraine in the same locality cannot escape notice. A few miles to the west of West Waterville a terminal or front moraine is thrown across the neck of the lake, forming a barrier to which this sheet of water owes its existence. Half-way between Waterville and West Waterville are fine polished and striated surfaces. At Clinton, as also between Etna and Newport, the marks are very distinct. In all these localities the lines run due north and south. To the west of Bangor the country is rolling and rather flat. Here the *roches moutonnées* are numerous, with polished surfaces, upon which the scratches and grooves are very distinct, but bearing generally north-northwest, over beds of slaty rock striking northeast. These rocks are partially covered by drift, in which scratched pebbles are not rare, though it contains but few large boulders. In the immediate neighborhood of Bangor, and especially near Pushaw Lake, the *roches moutonnées* are very extensive, and, from their character, particularly instructive. These rolling hills are formed by thin upturned clay-slate beds, standing edgewise, in

a vertical position, and striking east-northeast. Scratches, grooves, and furrows of every dimension, sometimes very distinct, sometimes fainter, but always rectilinear and always running due north, traverse the edges of these beds at right angles with the surfaces of stratification and the trend of the beds. It is evident that here there can be no confounding of the glacial marks with structural lines, or cracks in the strata, — for these would not run at right angles with the structure of the rock itself; or with furrows made by water, — for these would have followed the strata instead of crossing them; or with any displacement of the beds moving upon one another, — a suggestion which has sometimes been made to explain the appearance of these marks upon horizontal surfaces. Nor is there any trace of the angular ledges which must have resulted from the tilting of these stratified rocks. The whole region is levelled and smoothed down to an undulating plain.

While investigating the facts in this locality, I could not but recall the criticism of the "greatest geologist of the age" * upon the glacial theory, then in its infancy; and the ridicule thrown upon the idea that the polished and scratched rocks of the valley of Hasli had been fashioned by ice. He considered these appearances as the natural effects of the shrinking of melted masses under the process of cooling, which might produce some displacement or movement of successive layers one upon another, leading to marks of different kinds belonging to the structure of the rock itself, and not due to any external action. Had the strata in this instance been vertical in their position, like those of which the *roches moutonnées* on Pushaw Lake consist, instead of slanting but slightly, like those of the valley of Hasli, such an interpretation could not have been admitted for a moment, and the doctrine of a former greater extension of glaciers would perhaps have been recognized twenty-five years earlier by scientific men.

* Leopold von Buch.

From Bangor eastward to Eastport, I have made but a hasty survey,—not in the present journey, which included only the country between the Katahdin Iron Works and Mount Desert, but on a former occasion. I then noticed, that, at intervals, between Bangor and Calais and over the whole track from Calais to Eastport, numerous polished surfaces are visible, with distinct scratches and furrows pointing due north. I may say, therefore, from my own personal observation, that the State of Maine, for nearly its whole width, that is, over four degrees of longitude, and between latitude 44° and 45° , bears all the characteristic indications of glacial action on its surface. But while many of these phenomena are perfectly simple and clear to one intimately acquainted with the effects produced by moving masses of ice, I have noticed near Bangor, and more especially in the neighborhood of Waterville, facts not so readily explained, though I believe I have found their true solution. Ordinarily all the glacial marks in a given locality run in one direction, and have certainly been produced simultaneously by one and the same agent, however opinions may differ as to the nature of that agent. But on Ledge Hill, five and a half miles from Bangor, faint striæ may be seen pointing due north, while upon the same slab are other lines pointing northwest, forming an angle of forty-five degrees with the first. I believe that here we have two successive sets of lines, the later ones having partially obliterated the first. The height of the ridge may have determined a change in the course of the ice, when it had diminished in thickness, and no longer acted with the same undeviating force. At Waterville the facts are still more perplexing. On the road to Benton, near the house of G. W. Drummond, are slaty rocks striking northeast, upon the surface of which are again two sets of marks,—one consisting of large, distinct scratches and furrows trending due north, while the others are finer, less distinct, and point east-northeast.

On the road to Winslow, near the house of Henry Gichell, the same two systems of scratches may be seen on flat slabs of rock along the roadside. From the formation of the land in this region, I am inclined to believe the second agent—namely, that to which the scratches bearing east should be ascribed—to have been icebergs. There is high land two or three miles beyond these rocky surfaces, in Benton township; and the flat over which the Sebasticook River flows extends to these heights. The ice is likely to have remained longer upon the higher ground, and when the lower tracts were inundated by the melting of the general sheet of ice, the water, as it rose, may have floated off the remaining bergs, and drifted them across the normal primary scratches bearing due north.

On our return from the Katahdin Iron Works our road lay through Brownville, Orneville, Bradford, Hudson, and then along the shore of Pushaw Lake, to Bangor. Throughout this whole tract scratched and polished surfaces and *roches moutonnées* are frequent. But the most instructive localities of all, in reference to glacial phenomena, are to be found near the slate quarries of Brownville. Here again, as in the *roches moutonnées* at Pushaw Lake, the marks run at right angles with the trend and dip of the beds. To explain fully the significance of the facts in this region, I must say something of its general formation. Pleasant River runs through a wide, open valley, the direction of which is very nearly from north to south. The finely laminated clay beds in which the slate quarries are excavated are lifted to an angle of seventy degrees and more, that is, standing almost vertically; and their trend is across the valley from east to west, at right angles with it. More favorable circumstances for the study of glacial erosion could hardly be found. On comparing the marks and polished surfaces which pass at right angles over the edges of these upturned slate beds in the bottom of the

valley as well as upon its sides, they are found to have exactly the same direction, due north, as the valley itself, so that evidently the agent which produced them must have been instrumental in shaping this trough, as it moved down the valley, before it could follow its path unimpeded by any inequalities of surface. Had it been a fluid mass, it would have fitted itself to the lay of the land: it would have followed the vertical edges of the strata, working its way in between them, instead of cutting them all to one evenly rounded surface, as it has done. And indeed it would seem as if this place were meant to facilitate the task of the investigator. It presents the data for an immediate comparison between the action of water and that of ice, the limit of the former being distinctly visible in the narrow furrow at the bottom of the valley in which the river has cut its bed. This furrow is sunk somewhat below the general undulating level of the slate beds, and upon its surface there is no trace of rectilinear lines and grooves, but simply the usual irregular, winding marks arising from the action of running water, and following all the structural inequalities. The valley as a whole is a rather shallow depression, sinking a little more sharply toward the centre, and rising gradually east and west of the river-banks. The whole rock surface, with the exception of the river-bed, is glaciated, and it is impossible to overlook the fact that the same agent which has fashioned the bottom of the valley up to the adjoining hills has also grooved and scratched, at right angles with their structure, the upturned beds trending across it.

The absence of angular ledges in a region exclusively composed of uplifted slaty rocks is very remarkable. Facts like these show that a careful survey may furnish the means of actually measuring the extent of denudation or abrasion resulting from the grinding power of glaciers. They may even settle the question as to the origin of lake-basins now under discussion among geologists. The extensive excavations made

by the quarrying operations in these rocks give the most admirable chances for investigation. These slates are themselves of admirable quality, and very extensively used as roofing-slates. About a mile to the west of the quarries, near Merrill, there are large morainic accumulations of loose materials of the kind I have called bottom or ground moraines, though here they are not exactly in the form of horsebacks. Immediately above the quarries at Brownville, where the drift has been recently removed to facilitate the quarrying, there are good sections where these bottom moraines, trending in the direction of the hills to the east of the valley, may be easily studied. They rest immediately upon the edges of the upturned beds, the whole mass being a mixture of the most heterogeneous rocky materials uniformly mixed. Nowhere in this neighborhood have I seen anything like a distinct lateral moraine; but near the church, an unmistakable terminal moraine, across which the river has cut its bed, spans the valley. The exhibition of glacial phenomena is so complete here, that it seems superfluous to follow similar facts through localities where, owing to the character of the rocks and the lay of the land, they are less distinct. As, however, the extent over which the same set of phenomena may be traced forms an important part of the inquiry, I may indicate a few other points at which similar appearances occur. On the summit of the hill half-way between Brownville and Milo, near the Sebec River, the scratches and furrows are distinctly seen trending due north and south. They recur, after crossing the ferry, on the brow of another hill farther to the south. Between Orneville and North Bradford there are extensive flats, on which the rocks, wherever they are not decomposed, exhibit even and polished surfaces traversed by rectilinear grooves and furrows, trending mainly from north to south, though here and there diverging to the west, and even forming occasionally an angle of from twenty to twenty-five degrees

with the main set of lines. Farther south, as the land begins to rise again, all the marks point once more uniformly northward. To the north and south of the town of Hudson, and especially near the post-office, the scratches are very distinct, bearing due north across slaty rocks, which trend east-north-east. The views from the high lands over all this region are very beautiful. O'Lammon, the Peaked Mountains, and the Union River Mountains limit the horizon in the east; Dix's Mountain rises in the distance on the west; while the Katahdin Mountains are still visible far to the north.

On returning to Bangor, I proceeded at once, according to my original intention, to Mount Desert; but before giving an account of the glacial phenomena on that island, I must say a few words of the physical features of the country between Bangor and the sea. This region is intersected by three distinct ranges of hills, without counting the low range between Brewer and Holden. The first divides the valley of the Penobscot from that of Union River, passing through the townships of Clifton, Holden, and Dedham; the second separates the valley of the Union River from the Coast Range; the third is the Coast Range itself, of which Mount Desert and the elevated islands on either side of it form a part; for all these islands, so broken and picturesque in their outlines, must be looked upon as the higher summits of a partly submerged mountainous ridge. These chains do not run exactly parallel with the coast, their trend being more to the north than that of the shore itself; so that the ridges extending from east to west, across the country, are not exactly at right angles with the normal direction of the glacier marks, though nearly so. It is this formation of the surface of the land which makes the glacial phenomena so interesting between Bangor and the sea, especially where one can connect them with like traces farther north. The road from Bangor to Mount Desert passes in succession over all these ridges, ascending to the heights

and descending into the intervening depressions; thus rising three times from the bottom of a valley over the ridge intervening between it and the next valley, before reaching the southern coast of the large shore islands.* Over all the elevations and in all the valley bottoms one may trace, in unbroken continuity, and almost at right angles with the direction of the mountains and of the valleys, the same set of lines or glacial marks that we have already traced to the north of Bangor, running due north and south until they disappear under the arm of the sea which separates Mount Desert from the coast. They reappear on the north shore of the island itself, passing over its higher summits to lose themselves finally, under the level of the ocean. Not only are the characteristic marks to be followed along the entire length of the road, but the whole surface of the country is *moutonnée*; namely, worn into those rounded, knoll-like surfaces so frequently alluded to in this and previous articles, and so well known in Switzerland as due to glacial action. Bald Mountain is a striking example of this kind of hill.

This region is literally strewn with huge boulders, sometimes forty or fifty feet high. For the most part they seem to belong to the neighboring hills, and have not travelled a great distance. There are many of these boulders, however, which add their testimony to show that the path of the great ice-plough has been from north to south. This is especially the case with the granite rock of Dedham, so well characterized by its large feldspar crystals, detached masses of which are frequently found to the south of that locality, but never to the north of it. Occasional boulders of a much more northern origin are not wanting. Another link in the evidence is that, wherever the marks are preserved on any abruptly rising ground, they occur on its northern side, and do not appear on the southern one. Evidently the abrading agent advanced from

* Compare Chace's map of Maine.

the north, pushed up and over the face presented to it, while the southern face was comparatively protected, the rigid

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definite! What a scientific
datum! - But he don't say
whether ice in the bottom of
a Glen can be there at all -
He thinks it may take a
flying leap across a Glen!

p 11.

the north, pushed up and over the face presented to it, while the southern face was comparatively protected, the rigid mass no doubt often bridging the opposite declivity without even touching it. I suppose these facts, which perhaps seem insignificant in themselves, must be far less expressive to the general observer than to one who has seen this whole set of phenomena in active operation. To me they have been for many years so familiar in the Alpine valleys, and their aspect in those regions is so identical with the facts above described, that, paradoxical as the statement may seem, the presence of the ice is now an unimportant element to me in the study of glacial phenomena. It is no more essential to the investigator, who has once seen its connection with the facts, than is the flesh which once clothed it to the anatomist who studies the skeleton of a fossil animal. In the face of these facts it seems preposterous to assume that the loose materials and boulders scattered over this interval should have been stranded by icebergs driven inward from the sea-shore by currents or tidal waves. The whole movement, whatever its cause, was unquestionably in the opposite direction. The testimony of the loose materials and erratic boulders is the same all over the United States. They are always of northern birth. I have never seen a single fragment of rock from any more southern locality resting upon glaciated surfaces to the north of them, though I have searched for them from the Atlantic coast to Iowa.

The picturesque island of Mount Desert lies on the southern shore of Maine, in Hancock County, and is separated from the mainland by a narrow arm of the sea. Much higher in the centre than on the margin, its mountains seem, as one draws near, to rise abruptly from the sea. It is cleft through the middle by a deep fiord, known as *Somes Sound*, dividing the southern half of the island into two unequal portions; and its shores are indented by countless bays and coves,

which add greatly to its beauty. We entered the island on the northwestern side from Trenton, and proceeded at once to Bar Harbor, on the eastern side, a favorite resort in summer on account of its broken, varied shore, and of the neighborhood of Green Mountain, with its exquisite lake, sunk in a cup-like depression half-way up the mountain-side, and its magnificent view from the summit. At the very entrance to the island, on passing over the toll-bridge of Trenton, there is an excellent locality for glacial tracks. The *striae* are admirably well preserved on some ledges at the Mount Desert end of the bridge. The trend of these marks is north-northeast, instead of due north as in most localities; and here is one of the instances where this slight deflection of the lines is evidently due to the lay of the land. The island is not only highest towards the centre, but narrows at its northern end as it sinks toward the shore, from which it is separated on either side by two deep fiords running up into the coast of Maine, and known as *Frenchman's Bay* on the east, and *Union Bay* on the west. It is evident that the mass of ice passing from the mainland over this arm of the sea sunk eastward and westward into these two gorges, acquiring, no doubt, additional thickness thereby, and, in consequence of this change in its normal course, was slightly deflected from its usual direction in working its way up against the shore of Mount Desert. This is shown by the fact that the glacial marks on the northwest shore bear, as I have already said, slightly to the east, while those on the northeast shore bear slightly to the west. On approaching the centre of the island the marks converge towards each other, and regain their primitive direction due north and south, on its more elevated positions. I have often observed in Switzerland like instances, when from some local cause the direction of the movement was slightly deflected to the right and left, converging again at some little distance. In the valley of Hasli, between the Hospice of the Grimsel

Possibly but not probably. March 9. 1873 JH



and Guttanen, are several knolls which afford examples in point. On the upper side of these knolls, facing the higher part of the valley, from which large glaciers formerly came down, marks are carried directly up the slope on to the back of the knoll, while on either side they fall away slightly to the right and left, converging again to meet and continue their straight course over the lower slope; showing that, though such knolls, entirely buried beneath the mass of the ice, are no obstacle to its advance, the inequalities of the bottom do affect in a slight degree the direction of the movement, and render the striæ less even than over a level surface. Of course, where the ice is very thick, bottom inequalities will make little impression upon the onward movement of the whole mass; but in proportion as the ice grows less, it adapts itself to the depressions and knolls of the surface, in consequence of which the glacial marks lose the uniformity of their trend.

The morning following my arrival at Bar Harbor I spent in examining the glacial phenomena in its immediate neighborhood. At Bar Harbor itself, the marks bear north and north-northwest. A mile farther south they are all in a north-northwesterly direction. The cove of the Spouting-Horn, however, — a deep recess in the rock, where the surf acts with wonderful force, — is engraved on both sides with lines running due north. On the same side of the island, considerably to the south of Bar Harbor, there is a striking sea-wall composed of coarse materials, thrown up in a line along the shore, formed, no doubt, by some unusually severe storm, coinciding with high-water. It resembles the well-known sea-wall of Chelsea Beach. Behind this wall stretches an extensive marsh, formerly a part of the sea. Somewhat beyond it, on the shore, are two very distinct polished and grooved surfaces, with the lines running due north. On the afternoon of the same day, I ascended Green Mountain. Along the lower part of the road the marks run northwest, then north-

northwest, converging more and more toward their normal course, until, after passing the first summit, and thence upward, they lose entirely the slanting direction impressed upon them by the deflection of the ice about Frenchman's Bay, and run due north again. All the way up the last slope of the mountain, wherever the rock is exposed, may be seen well-engraved flat surfaces of rose-colored protogyne, on which the scratches and grooves sometimes run for twenty feet without any perceptible interruption. On the very summit is a quartz dike cut to the same level with the general outline of the knoll, on which the marks are very distinct. I arrived on the extreme point, where the southern descent is so abrupt that the mountain seems to plunge into the ocean, just at sunset. The sea as far as the eye could reach was still glowing with color; amethyst clouds floated over the numerous islands to the southwest; while on the other side in the gathering shadows lay the little lake midway on the mountain slope, and, below, the many inlets, coves, and islands of Frenchman's Bay.

On the following day, we crossed to the opposite side of the island, skirting *Somes Sound*, and the next morning entered the sound in a small schooner. A stiff breeze from the north, which obliged us to tack constantly, and made our progress very slow, prevented us from exploring this singular inlet for its whole length; but short as it was, our sail gave me ample opportunity for observing the glacial phenomena along its shores. At the mouth of the sound, before entering the narrows, there are several concentric terminal moraines on both sides of the fiord. No doubt they once stretched across it, and have been broken through by the sea. On either side, to the right and left, in ascending the sound, are little valleys running down to the water; and evidently they have all had their local glaciers, for there are terminal moraines at the mouth of each one. These facts only confirmed my anticipations. I had seen, on passing

the head of the fiord, in our drive of the previous day, that it must from its formation afford an admirable locality for glacial remains, unless they had been swept away by the sea. The small town of Somesville is beautifully situated at the head of the sound. Approaching it from the east, I observed that the glacial marks which had been pointing due north began to point west-north-west, while on the western side of the settlement they pointed east-northeast. Evidently there is an action here similar to that by which the marks are deflected on the northern shore of the island about Frenchman's Bay and Union Bay. The mass of ice coming from the north had been gradually sinking into the fiord from opposite sides. Near Somesville church the marks run again due north.

The extensive surfaces of polished and scratched rocks in this locality recall the celebrated Helle-Platten of the valley of Hasli. From Southwest Harbor we followed the shore to Bass Harbor and Seal Cove. There are frequent indications of glacial action along this road, and one or two points of special interest. At Bass Harbor there is a large dike of green trap running at right angles with the tide current. Though regularly overflowed at high-water, the action of the sea has not affected the glacial characters, which are peculiarly distinct at this spot. Not only is the surface of the dike itself deeply scored with striæ and furrows running due north, but, being of a softer quality than the granitic rock which it intersects, it has been cut to a little lower level, and the vertical walls of the fissure are polished, scratched, and grooved in the same way. I met here with one of those incidents showing the character of the working-class in America which always strike a European with astonishment. There was a blacksmith's shop near this dike, and being extremely anxious to obtain a specimen from it on account of the clearness of its glacial characters, I requested the head workman, who had been watching my observations with a good deal

of interest, to break me off a piece. It was not an easy task, for there were no angles, the dike being sunk below the surrounding surface and perfectly smooth. After a time, and not without some hard work, a wedge was driven in, and with the help of a crow-bar two or three very satisfactory specimens were pried out. I naturally wished to pay the man for his labor; but he refused to take anything, saying that he saw I was a geologist travelling for the sake of investigation. He added, that he subscribed for one or two papers and magazines: perhaps he should meet with some of the published results of my journey one of these days, and that would be the best reward for the little help he had given. Seeing his interest in the object of my researches, I explained to him the significance of this dike, showed him the direction of the marks pointing straight to the north, and evidently entirely independent of tidal action, since they ran at right angles with it. As I bade him good by, he said, "Henceforth this dike shall be my compass; I shall know when the wind blows due north." The locality was, indeed, especially interesting from several points of view. It is one of the few instances I have seen in which a dike, being composed of a softer paste than the adjoining rock, has yielded more readily to the ice-plough, and is cut to a lower level, thus forming a broad, flat furrow, the upright walls of which are scored as deeply as the horizontal surface of the dike. Another most important fact is, that the tide daily flows across these marks. Evidently, then, they have not been made by water, since water has no power to erase them, or to obscure them by other lines of the same kind. A mile and a half to the south of Bass Harbor there is a ledge facing north, on which the glacial characters also point to the north. At Seal Cove, however, on the southwestern shore, the marks have again a north-northwesterly direction. South of Seal Cove all the surface inequalities are *moutonnées*, the striæ running north-northwest. We

| Play

returned to Trenton bridge by the western shore, having thus skirted the whole island.

Before closing these remarks I wish to allude, in passing, to some other facts connected with this investigation, which I could not easily notice at an earlier time without interrupting my narrative. East and south of Bangor there are considerable deposits of faintly laminated clays, used for the manufacture of bricks, in which striated pebbles and patches of sand are sparsely interspread. I take it for granted that the clays are morainic materials remodelled by the floods arising from the melting of the great glaciers, and the pebbles and sands the droppings of icebergs floating upon these waters. This is the more probable, since accumulations of irregularly stratified sand are always found in the vicinity of such masses of sifted clays, containing scratched pebbles. I have seen similar deposits in the Western Slates, for instance, near Milwaukee and Chicago.

Between Bangor and Mount Desert the usual evidence of glaciation is very extensive. I would mention as particularly interesting the hills south of Holden and the hills about Dedham. On the route along Union Bay there are also extensive polished surfaces, especially in the vicinity of Bucksport. Near Ellsworth they are beautifully preserved, and all the eminences are *moutonneés*. At Ellsworth Falls, on both sides of the bridge, there are splendid polished surfaces, with scratches and furrows pointing due north. Between Ellsworth and Trenton, and westward of that meridian, in the direction of Bucksport, there are several longitudinal moraines parallel to one another, running from north to south, composed of large, angular boulders, resting upon ground moraines made up of rounded, scratched pebbles and sand mixed with clay. Such a superposition is utterly incompatible with the idea of currents passing over these tracks. Two miles west of Ellsworth a similar longitudinal moraine runs over the top of the hill, and about one mile farther west there is

another, chiefly composed of the coarse Dedham granite. The bottom deposit, upon which these moraines rest, consists of fine sand and loam with scratched pebbles. Seven or eight miles west of West Ellsworth the hills, consisting of clay slates on edge, trending from east to west, are abraded, and upon the polished surfaces of their levelled edges rest two other longitudinal moraines, with angular boulders of Dedham granite, running from north to south, and resting upon an extensive ground moraine containing many smaller rounded and striated boulders. Ten miles west of Ellsworth there is still another longitudinal moraine; but the largest of all these parallel moraines is about three miles farther west, that is, about thirteen miles west of Ellsworth. Half a mile south of Bucksport the clay slates are nearly vertical, and their upturned edges are evenly polished and scratched. These surfaces are partially covered with the mud of the Penobscot River. Similar facts may be traced all the way between Bucksport and Bangor. Everywhere the scratches point due north.

The coast range east and west of Somes Sound is divided into a series of hills by transverse valleys, in most of which there are small lakes formed by transverse moraines at their southern extremity. Beginning east, and not counting the less-prominent peaks, we have, first, Newport Mountain; next, Kebo and Green Mountains; then, Jordan Mountain, Bobbey Mountain, Hadlock or Pond Mountain, and Westcot Mountain, all to the east of Somes Sound; then follow Dog Mountain, Defile Mountain, Beach Hill, and West Mountain, all on the west side of Somes Sound. Denning's Pond, which I have examined more in detail, lies between Dog Mountain and Defile Mountain. The road along the lake follows the eastern or left lateral moraine of the glacier which once filled its basin; and the lake itself is hemmed in by a crescent-shaped terminal moraine at its southern extremity. The lakes, eleven in number, intervening between the

other mountains, are likewise bordered by moraines. We have thus satisfactory evidence that at an early period of the retreat of the great ice-field covering this continent, when it no longer moved over the highest summits of the land, local glaciers were left in the gorges facing the sea.

We have thus traced the glaciated surfaces over the whole width of the State of Maine, and over a part of its length, in a narrow track some hundred miles in extent, from the Katahdin Iron Works to the southern shore of Mount Desert, where they are lost in the ocean. I have, however, suppressed a great amount of evidence which could not easily be presented without maps and sections. I may have an opportunity of publishing what has been omitted on some future occasion. Over this whole region, the glacial characters run due north and south, never deflected except by local causes, ascending, in undeviating rectilinear course, all the elevations, and descending into all the depressions. How is it possible to suppose that floating icebergs would advance over such an uneven country with this steadfast, straightforward march? Instead of ascending the hills, they would be caught between them in the intervening depressions, or, if the land were completely submerged, floated over them. The advocates of the iceberg theory forget also that an amount of floating ice, so much larger than is now annually spreading over the Northern Atlantic, implies a far lower temperature; and with it we have the conditions necessary to cover the mainland with glaciers, instead of simply increasing the field of icebergs. Equally impossible is it to suppose that anything so unstable as water has produced such straight and continuous lines.

Assuming, then, that these phenomena were produced by ice, let me add, in conclusion, that the glacial traces over the State of Maine, and especially between Bangor and the sea-coast, afford means of estimating approximately the thickness of the ice-sheet which once moved over the whole land, as well as its limitations during a later period, when it had begun to wane. In order to advance across a hilly country and over mountainous ridges rising to a height of twelve and fifteen hundred feet in the southern part of the State, and to a much higher level in its northern portion, the ice must have been several times thicker than the height of the inequalities over which it passed; otherwise it would have become encased between these elevations, which would have acted as walls to enclose it. We are therefore justified in supposing that the ice-fields, when they poured from the north over New England to the sea, had a thickness of at least five or six thousand feet. On a future occasion I shall give an account of the drift phenomena along our Atlantic coast, showing also that at that period the ice-fields were not bounded by our present shore line, but extended considerably beyond it, over surfaces now occupied by the ocean. At a later time, during the shrinking and gradual disappearance of the ice-sheet, the ice, no doubt, retreated within the shore-islands. The aspect of the coast of New England must then have been very similar to that of Greenland in its colder portions. Mount Desert itself must have been a miniature Spitzbergen, and colossal icebergs floated off from Somes Sound into the Atlantic Ocean, as they do now-a-days from Magdalena Bay.

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